Refine Search

Search Results -

Terms	Documents
L5 and L16	1

Database:
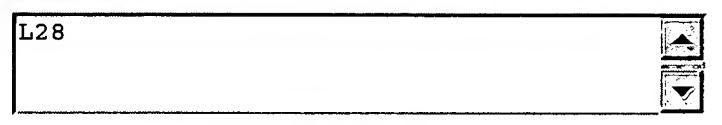US Pre-Grant Publication Full-Text Database
US Patents Full-Text Database
US OCR Full-Text Database
EPO Abstracts Database
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Derwent World Patents Index
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Search: L28

[Refine Search]

[Recall Text ◆]   [Clear]   [Interrupt]

Search History

DATE: Sunday, February 05, 2006   Printable Copy   Create Case

Set Name side by side	Query	Hit Count	Set Name result set
	DB=PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD; PLUR=YES; OP=OR		
L28	l5 and l16	1	L28
L27	l16 and L26	1	L27
L26	angular same orbit	3959	L26
L25	l16 and L24	0	L25
L24	angular near4 orbit	613	L24
L23	l16 and L22	0	L23
L22	angular near orbit	107	L22
L21	L11 and l16	0	L21
L20	inertial and l16	1	L20
L19	l17 and L18	1	L19
L18	time or period or interval	8856816	L18
L17	l15 and L16	1	L17
L16	5412574.pn.	2	L16
L15	calculat$	1664699	L15
L14	l10 and L13	8	L14
L13	circular	1473900	L13
L12	l10 and L11	5	L12

L11	velocity	673292	L11
L10	l8 and L9	12	L10
L9	attitude or angular	830514	L9
L8	l6 and L7	13	L8
L7	(sens$3 or track$3) adj (star or (bright adj object))	548	L7
L6	l4 and L5	21279	L6
L5	stayout or exclusion	96125	L5
L4	l1 or L2	2029365	L4
L3	l1 oe L2	9128541	L3
L2	vehicle	2016307	L2
L1	space$craft or (space adj craft)	19424	L1

END OF SEARCH HISTORY

Refine Search

Search Results -

Terms	Documents
L6 and L7	13

Database:
US Pre-Grant Publication Full-Text Database
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Search: L8

[Refine Search]

[Recall Text] [Clear] [Interrupt]

Search History

DATE: Sunday, February 05, 2006   Printable Copy   Create Case

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L8	l6 and L7	13	L8
L7	(sens$3 or track$3) adj (star or (bright adj object))	548	L7
L6	l4 and L5	21279	L6
L5	stayout or exclusion	96125	L5
L4	l1 or L2	2029365	L4
L3	l1 oe L2	9128541	L3
L2	vehicle	2016307	L2
L1	space$craft or (space adj craft)	19424	L1

END OF SEARCH HISTORY

L14: Entry 5 of 8   File: USPT   May 2, 1995

DOCUMENT-IDENTIFIER: US 5412574 A
TITLE: Method of attitude determination using earth and star sensors

Abstract Text (1):
A method of attitude measurement for an artificial satellite (100) utilizes one or more star
trackers (12) together with an earth sensor (30). Periodic updates of satellite orbital
information, either propagated onboard or from a ground station are combined with earth and star
position coordinate data to provide a continuous and accurate measurement of the spacecraft body
3-axis attitude. The method can be used for ground-based attitude determination or onboard closed
loop control systems.

Brief Summary Text (3):
The present invention broadly relates to determining and controlling spacecraft 3-axis attitude.

Brief Summary Text (5):
Artificial satellites and other spacecraft are in widespread use for various purposes including
scientific research and communications. Many scientific and communications missions cannot be
accurately fulfilled without consistently monitoring and controlling the spacecraft 3-axis
attitude. In many applications the satellite must be positioned to direct communication signals in
particular directions or to receive signals from specifically located sources. Without accurate
control over spacecraft 3-axis attitude, the transmission of such signals is hindered and at times
impossible.

Brief Summary Text (6):
Most modern spacecraft have 3-axis attitude control apparatus and methods included; however, these
have several drawbacks or shortcomings. One method includes an earth sensor for two axes (i.e.
roll and pitch) and continuous gyros with periodic sun sensor updates for the third axis (i.e.
yaw). This technology is heavy, expensive, requires high power and is unreliable for long-life
missions on the order of 10 to 15 years.

Brief Summary Text (7):
Alternative methods include those disclosed in U.S. Pat. No. 5,054,719 issued to P. A. Alexandre
Maute, Oct. 8, 1991, and U.S. Pat. No. 5,107,434 issued to Michael A. Paluszek, Apr. 21, 1992. In
each of these two patents, polaris star sensors and earth or sun sensors are used. These two
configurations have several limitations and drawbacks. First, polaris star sensors must be
oriented northward toward the inertial polar axis. In the case of 3-axis stabilized geosynchronous
satellites, accurate polaris sensing with constant northward orientation is problematic since
solar panels will cause glint in the polaris star sensor's field of vision. Therefore, either
extremely long sunshades and/or long mounting booms are required to ensure proper sensing of the
desired polar star. Sunshades or mounting booms add additional weight to a spacecraft which,
obviously, is undesirable. Further, when a star tracker is boom-mounted, essentially
uncalibratable flexible vibration and distortions of the boom greatly reduce the accuracy of the
system. Finally, systems utilizing polaris star sensors can only be used in low inclination
orbits. Continuously directing a polaris star sensor towards a polar star in a high inclination
orbit is difficult because a mounting location may not be found to provide continuous northward
orientation of the sensor.

Brief Summary Text (8):
A third known method used to control 3-axis attitude includes using general purpose star sensors
alone. At least two star sensors are required for this method and typically at least 3 are used
for redundancy. The additional star sensor in this instance imposes additional weight, power, cost
and mounting space requirements on the spacecraft system. One star tracker can track multiple
stars and estimate 3-axis attitude measurements by itself; however, its accuracy is a function of

star separation within its field of vision. Reasonable accuracy requires a minimum star separation. The required value of star separation within the field of vision is not always guaranteed. In order to guarantee accuracy using only general purpose star sensors requires at least two operational star sensors activated at the same time.

Brief Summary Text (9):
The inventive method is an improvement over the prior art because it avoids many of the difficulties inherent in determining and controlling 3-axis attitude using polaris star sensors or general purpose star sensors alone. The inventive method employs a general purpose star tracker and a terrestrial body sensor to provide continuous and accurate 3-axis attitude estimation and control.

Brief Summary Text (11):
The method of the present invention determines the attitude of a spacecraft in a preselected orbit by using a star tracker, a terrestrial sensor and periodic updates of spacecraft orbit information. The method of the present invention includes six basic steps. First, measure the position of the earth relative to the spacecraft using the terrestrial body sensor. Second, determine a set of coordinate data that defines the position of the earth relative to the spacecraft orbit. Third, measure the positions of a plurality of stars within the star tracker's field of vision relative to the star tracker. Fourth, determine a set of coordinate data that defines the positions of the stars within the star tracker's field of vision relative to the spacecraft. Fifth, determine a set of coordinate data that defines the positions of the same stars relative to the spacecraft orbit. Lastly, determine the spacecraft 3-axis attitude using the measured position of the earth and the several sets of coordinate data that define: the position of the earth relative to the spacecraft orbit, the position of the earth relative to the spacecraft, the positions of the stars relative to the spacecraft, and the positions of the stars relative to the spacecraft orbit, respectively.

Brief Summary Text (12):
The method of the present invention provides a continuous and accurate estimate of spacecraft 3-axis attitude using a combination of star and earth position measurements with periodic updates of spacecraft orbit information. One or more general purpose star trackers are used together with any sensor that will provide measurements of earth position.

Brief Summary Text (13):
General purpose star trackers employed in connection with the present invention must be capable of star acquisition, tracking and identification in any part of the sky. The star sensors image light from stars onto a detector, discriminate between stars and other detected light, determine what stars to track and identify those stars using an onboard star catalog. Star positions are reported in sensor referenced and inertially referenced coordinates. Star data from the trackers is combined with earth position measurements taken from the earth position sensor. The earth position sensor can be a carbon dioxide band type earth sensor or a ground based RF beacon type sensor. The reference coordinates of the star data and the earth position in combination with orbit information periodically updated from the ground provide the necessary information to determine the spacecraft 3-axis attitude.

Drawing Description Text (3):
FIG. 1(b) illustrates the relationship between a star tracker reference frame and the spacecraft body frame.

Detailed Description Text (3):
The spacecraft body frame (B) 108 has its origin at the center of the satellite 100. The x-axis 110 is the roll axis. The y-axis 112 is the satellite pitch axis. The z-axis 114 is the satellite yaw axis, that is pointed toward earth nadir.

Detailed Description Text (4):
The spacecraft orbit frame or reference frame (R) 116 is nominally coincident with spacecraft body frame 108. Reference frame 116 has its 1-axis 118 coincident with the body frame x-axis 110. Reference frame 116 has its 2-axis 120 coincident with body frame y-axis 112. 3-axis 122 is coincident with z-axis 114. Although reference frame 116 is illustrated coincident with spacecraft body frame 108, these two frames of reference will not always be aligned.

Detailed Description Text (6):
The relationship between celestial frame 124 and the spacecraft orbit or reference frame 116 is

described by three variables: the orbit inclination, i, 134, illustrated as measured in the equatorial plane; the right ascension of the ascending node, .OMEGA. 136 illustrated as measured in the equatorial plane; and the time of day angle, .theta..sub.2, 138 which varies linearly from zero to 360 degrees through a single day as measured in the equatorial plane.

Detailed Description Text (7):
FIG. 1 (b) illustrates the fourth reference frame associated with the method of the present invention. Star tracker reference frame (S) 140 is illustrated relative to the spacecraft body frame 108. The a, b, and c axes 142, 144, and 146, respectively, represent the star tracker frame 140. The star tracker frame's axes are related to the x 110, y 112, and z 114 axes of the spacecraft body frame 108 as illustrated. To achieve the illustrated orientation, begin with a, b, c coincident with x, y, z. The star sensor boresight is along c. Rotate the tracker frame about the b-axis through .alpha..sub.AZ degrees, where .alpha..sub.AZ is the tracker azimuth mounting angle, described more fully below in relation to FIG. 3(a). Next, rotate about the a-axis through .epsilon..sub.EL degrees where .epsilon..sub.EL is the tracker elevation mounting angle, described more fully below in relation to FIG. 3(b). Finally, rotate about the c-axis by .gamma..sub.R, the rotation mounting angle of the star tracker.

Detailed Description Text (8):
FIG. 2 is a block diagram of a control system 10 for determining the 3-axis attitude of an earth orbiting satellite (not shown) along three axes, in accordance with the present invention. A plurality of star trackers 12 are linked to a central processing unit (CPU) 14. In actual implementation of the illustrated embodiment, this link may be through hardware such as hardwiring if CPU 14 is on-board the satellite, or linked in the sense that the star trackers 12 communicate with the CPU 14 through radio or microwave signals. Star trackers 12 acquire tracking information regarding stars within their field of vision from star acquisition means 16. The light from the stars is detected on a star detector (not shown). The detected or imaged light is then filtered to eliminate light sources other than stars. Star tracking means 18 then determines which stars to track. The illustrated embodiment further includes a star identifying means 20 of the type having the capability of internally identifying tracked stars through an onboard star catalog 22. Star identifying means 20 compare the input from tracking means 18 with onboard star catalog 22. The information gathered and processed by star trackers 12 is converted into digitized form by a digitizer 23 and then transferred to CPU 14.

Detailed Description Text (9):
The star trackers 12 employed in connection with the method of the present invention must have the ability to detect visible light and convert it to digitized electronic charge information. The star trackers 12 must also be able to acquire one or more stars while avoiding false image acquisition, track and centroid one or more stars subsequent to acquisition and identify the tracked stars using the onboard star catalog 22. The illustrated star trackers 12 have these capabilities internally, however, these functions can be equally well performed by a conventional separate digital processor (not shown).

Detailed Description Text (10):
Star tracker 12 has an output 24 that consists of averaged and normalized vector measurements 26, 28 of the positions of the identified stars relative to the spacecraft body and an orbit reference frame, respectively. The details of how these measurements are obtained is described more fully below.

Detailed Description Text (11):
An earth position sensor 30 is also connected to the CPU 14. Earth position sensor 30 can be any conventional sensor that measures earth position to facilitate an estimate of the attitude of the satellite along the 3-axes. Examples of such earth position sensors include a carbon dioxide band earth sensor or an RF ground beacon sensor. The earth position sensor 30 acquires and provides information regarding azimuth 32 and elevation 34 measurements of earth nadir or a preselected ground station. The nadir measurements will be necessary when a carbon dioxide band sensor is employed. When an RF ground beacon sensor is employed, the azimuth and elevation measurements will define a ground station having a known longitude and latitude.

Detailed Description Text (12):
Earth sensor 30 could be replaced with a cross-link sensor. A cross-link sensor would measure the position of a preselected artificial satellite or spacecraft relative to the cross-link sensor. One example of such a cross-link sensor would be an autotrack sensor that is an RF receiver that uses an RF beacon source. If a cross-link sensor is employed, terrestrial body position

measurements would be replaced by preselected beacon measurements, accordingly. The remainder of this discussion assumes an earth sensor 30 is employed.

Detailed Description Text (13):
CPU 14 collects averaged measurements 26, 28 from star trackers 12 and measurements 32, 34 from earth sensor 30, and processes them according to the inventive method described in detail below. The averaged values, S, R, are used to approximate the values of the necessary attitude determining variables; namely, the satellite body roll, pitch and yaw .phi.37, .theta.38, .PSI.39.

Detailed Description Text (14):
A satellite steering law is chosen and the earth position sensor 30 is mounted on the satellite body 100 such that it is oriented toward the earth 104 continuously throughout the satellite's orbit 106. The star tracker dynamic range is chosen and the star tracker 12 is mounted on the satellite body 100 to meet several requirements. For example, the earth position sensor boresight and the star tracker boresight must have good angular separation between them. The amount of angular separation required will depend on attitude determination accuracy requirements since the accuracy potential of any geometric configuration can be expressed as a function of boresight angular separation. Optimal accuracy is achieved with 90 degree angular separation. Worst case scenario accuracy results when angular separation is zero degrees. Acceptable accuracy is generally attained with angular separation of at least 30 degrees.

Detailed Description Text (15):
A minimum angular separation of at least 25 degrees must be maintained between the star tracker boresight and any light sources such as the moon or spacecraft appendages that may cause glint, to avoid "flooding" the star tracker detector with light. Examples of such appendages include antennas and solar panels.

Detailed Description Text (18):
FIGS. 3(a) and 3(b) illustrate one mounting configuration for the star tracker 12 that is appropriate for a geosynchronous communications satellite 100 with an earth nadir-pointing orbit-normal steering law in a zero inclination equatorial orbit. In FIG. 3(a) the essentially flat surfaces of two solar panels 40 are in the y-z plane. In FIG. 3(a), the y-axis would point downwards, normal into the surface of the paper. Solar panels 40, respectively extend outwardly from the north and south faces of the spacecraft body 100. Two large steerable antennas 43 extend nominally from the east and west faces of the spacecraft body 100, respectively. Antennas 43 have a range of motion in both azimuth and elevation directions. Star tracker boresight 42 has an azimuth mounting angle 44, .alpha..sub.AZ, relative to the negative z-axis, also known as the negative yaw axis in the roll-yaw plane.

Detailed Description Text (19):
Azimuth angle, .alpha..sub.AZ yields optimum accuracy at 90 degrees. However, spacecraft appendage stay-out zone requirements may not always permit an .alpha..sub.AZ orientation of 90 degrees. The illustrated spacecraft configuration includes a 25 degree stayout zone for spacecraft appendages. Therefore, optimal star tracker mounting includes .alpha..sub.AZ being as near 90 degrees as possible while providing 25 degrees clearance between all spacecraft appendages and the star tracker boresight 42.

Detailed Description Text (20):
FIG. 3(b) illustrates the same satellite 100 with star tracker 12 and solar panels 40 as viewed in the y-z plane also known as the pitch-yaw plane. Elevation angle 46, .epsilon..sub.EL, equals 53 degrees up from the roll-yaw plane. .epsilon..sub.EL is 53 degrees because the illustrated configuration includes a maximum sun declination equal to 23 degrees and a sun stayout requirement equal to 30 degrees. .epsilon..sub.EL is the sum of the sun declination and the sun stayout requirement. The sun stayout requirement is a function of the star tracker's sunshade design.

Detailed Description Text (21):
The illustrated configuration ensures that the sunline will never encroach a line extended at 30 degrees from star tracker boresight 42. Some angular separation also exists between the north solar panel 40 and star tracker boresight 42, thereby avoiding glint.

Detailed Description Text (26):
The earth position sensor 30 provides a vector measurement of earth nadir in the satellite body frame of reference 108. Earth position sensor 30 also generates a vector measurement of the same

earth position relative to the spacecraft orbit 106 using an ephemeral data base. The earth and star measurements in the two reference frames are equated through a variable attitude matrix providing the equations, in the appropriate unknowns, to determine the satellite 3-axis attitude.

Detailed Description Text (27):
The inventive method employed by the present control system depends on mathematical manipulation of star and earth position vector measurements. These measurements are achieved In the specific coordinate reference frames, illustrated in FIGS. 1(a) and 1(b), and are transformed from one frame to another. The reference frames utilized in the inventive method are a Star Tracker Frame 140, a Spacecraft Body Frame 108, an Orbiting Reference Frame 116 and a Celestial Frame 124.

Detailed Description Text (30):
There are three preferred transformations involved in the inventive method. First, the transformation from spacecraft body (B) to star tracker (S) coordinates is defined as: ##EQU1## Where .alpha..sub.AZ,j is the azimuth mounting angle 44, .epsilon..sub.EL,j is the elevation mounting angle 46 and .gamma..sub.R,j is the rotation mounting angle of the jth star tracker with respect to the spacecraft.

Detailed Description Text (31):
The variable j represents a star tracker in the range from 1 to n. In one embodiment n=2. M.sub.j is constant for j=1, . . . n and, therefore can be stored on board the spacecraft and used in the calculations to be described below.

Detailed Description Text (32):
Second, the transformation from orbiting reference frame (R) 116 to spacecraft body frame (B) 108 is defined as: ##EQU2##

Detailed Description Text (33):
Matrix A is the attitude matrix that describes the spacecraft attitude. Therefore, Matrix A is the solution matrix in the inventive method. Matrix A can be described in terms of Euler angles as: ##EQU3## Where .phi.37, .theta.38, .PSI.39, represent a 1-2-3 euler angles set; one of twelve possible Euler angle representations of A. Specifically, .phi. is the body roll pointing error, .theta. is the pitch pointing error and .PSI. is the yaw pointing error.

Detailed Description Text (35):
Defining the orbiting reference frame so that the attitude matrix represents a small rotation results in all twelve Euler angle representations, to first order, being equivalent. Therefore, when small angle assumptions are made, Matrix A can be written as: ##EQU5##

Detailed Description Text (37):
Third, the transformation from celestial frame (I) 124 to orbiting reference frame (R) 116 is defined as: ##STR1## Where i is the orbit inclination, .OMEGA. is the right ascension of the ascending node 13. .theta..sub.2 is the angle 138 proportional to the time of day. .theta..sub.2 varies linearly from zero to 360 degrees in a single day for a geosynchronous satellite; in a single orbit for a non-geosynchronous circular orbit.

Detailed Description Text (38):
Transformation C: I.fwdarw.R is time-varying in all constituent arguments. The time of day angle varies as described above. Gravitational factors cause the orbit inclination 134 and right ascension of the ascending node 136 to change over periods on the order of days and weeks. Angle .theta..sub.2 138 should be updated onboard the spacecraft every few seconds to update transformation C. Similarly, orbital elements i and .OMEGA. should be updated to update transformation C. Orbital elements i and .OMEGA. can be updated on board the spacecraft or on the ground on the order of every few days or weeks. Properly updating the parameters of transformation C ensures an accurate representation of that transformation and, therefore, accurate calculation of the attitude matrix as described below.

Detailed Description Text (41):
Third, earth position sensor provides earth vector measurements in spacecraft body coordinates B as: ##EQU8## Where, if the earth sensor 30 is an RF space-ground link, .theta..sub.EW is the azimuth and .theta..sub.NS is the elevation angle describing the position of a ground station with respect to earth nadir. .theta..sub.AZ 32 and .phi..sub.EL 34 are the space-ground link azimuth and elevation measurements with respect to the ground station respectively. If the earth sensor 30 is a carbon dioxide band sensor then, .theta..sub.EW and .theta..sub.NS are both equal to zero

and .theta..sub.AZ and .phi..sub.EL are azimuth and elevation angle measurements of the earth sensor with respect to earth nadir. The proper earth ephemeris data is given by the following notation: ##EQU9## which is analogous to star reference positions given from the star catalog 22.

Detailed Description Text (42):
The above described input data is then processed to determine the satellite 3-axis <u>attitude</u>. One embodiment includes equating measurements in the body frame B to reference information in the orbiting reference frame R through the transformation between these frames; A(.phi., .theta., .PSI.), the desired <u>attitude</u> matrix.

Detailed Description Text (44):
Equating the averaged measurements and the averaged references through rotation A yields: ##EQU11## Now, by substituting equation (4) into equations (10) and (11), rearranging terms and removing an extraneous equation yields: ##EQU12## This is a linear measurement equation expressed in terms of .phi., .theta. and .PSI.. The notation X.sub.avg,i (j) denotes the jth element of the 3-vector X.sub.avg,i. The least squares <u>attitude</u> estimate is then given by the equation: ##EQU13##

Detailed Description Text (45):
As discussed above, small angle approximations provide the simple form of the <u>attitude</u> matrix in equation (4) because such approximations are consistent with most steering laws employed by most communications and science satellites. In equations (8) and (9), the measurements of multiple stars from each star tracker and their corresponding references are averaged in cartesian coordinates providing one measurement from the star tracker, reducing subsequent computation and limiting data flow across the interface between the star trackers 12 and the CPU 14.

Detailed Description Text (47):
Any alternate <u>attitude</u> determination scheme (QUEST, for example) can be utilized to derive estimates of the <u>spacecraft attitude</u> from the various measurements.

Other Reference Publication (3):
SPIE vol. 641 Acquisition, Tracking and Pointing, 1986, <u>Attitude</u> Acquisition and Tracking Capabilities of the Instrument Pointing System by Jens A. Busing, Fred Urban.

Other Reference Publication (5):
SPIE vol. 1111, Acquisition, Tracking and Pointing III, 1989, The Enhancement of Armored <u>Vehicle</u> Fire Control (Stationary and Fire-On-The-Move) Performance Using Modern Control Techniques by John N. Groff.

CLAIMS:

1. A system for determining the 3-axis <u>attitude of a spacecraft</u> in a preselected orbit, comprising:

star sensing means on said <u>spacecraft</u> for sensing the positions of stars relative to said sensing means, and for producing first signals representing said star positions, said star sensing means including star trackers each having a field of vision aligned in a preselected direction and position with respect to said <u>spacecraft,</u> each of said star trackers including

(1) acquiring means for acquiring star position information describing stars within said field of vision.

(2) tracking means for <u>tracking said stars</u> within said field of vision.

(3) a star catalog.

(4) means for identifying said stars within said field of vision using said star position information and said star catalog, and

(5) digitizing means for digitizing said star position information into digitized representations of the positions of said stars relative to said <u>spacecraft and said spacecraft</u> orbit, respectively;

terrestrial body sensing means on said <u>spacecraft</u> for sensing the position of a terrestrial body

relative to said spacecraft, and for producing second signals representing said terrestrial body position; and

processing means for processing said first and second signals and for determining said 3-axis attitude of said spacecraft.

2. The system of claim 1 wherein each of said star trackers further comprises averaging the normalizing means for averaging and normalizing said digitized representations of said star positions to determine an averaged and normalized representation of said star positions relative to said spacecraft and said spacecraft orbit, respectively.

3. The system of claim 2 wherein said first signals comprise said digitized averaged and normalized representation of said star positions relative to said spacecraft and said spacecraft orbit, respectively.

4. A spacecraft attitude control system for determining the 3-axis attitude of a spacecraft in a preselected orbit, consisting essentially of:

star sensing means on said spacecraft for sensing the positions of stars relative to said sensing means, and for producing first signals representing said star positions;

cross-link sensing means on said spacecraft for sensing the position of a preselected RF beacon relative to said spacecraft, and for producing second signals representing said beacon position; and

processing means for processing said first and second signals and for determining said 3-axis attitude of said spacecraft.

6. The system of claim 5 wherein said RF receiver measures the position of said RF source relative to said spacecraft and said spacecraft orbit, respectively.

7. A method of determining the three axis attitude of a spacecraft in a preselected orbit, using star trackers on said spacecraft, an on-board star catalog and terrestrial sensor on said spacecraft, comprising the steps of:

(A) measuring the position of a terrestrial body with respect to said spacecraft, using said terrestrial sensor;

(B) generating a first set of coordinate data using said orbit, said first set of coordinate date defining the position of said terrestrial body relative to said spacecraft orbit;

(C) measuring the positions of each of a plurality of stars with respect to said star trackers, using said star trackers;

(D) generating a second set of coordinate data using the positions measured in step (C), said second set of coordinate data defining the positions of said stars relative to said spacecraft;

(E) identifying each star measured in step (C), using said star trackers and said on-board star catalog, to generate a third set of coordinate data, said third set of coordinate data defining the positions of said stars relative to said spacecraft orbit; and

(F) determining said attitude of said spacecraft using the position measured in step (A) and the first, second and third sets of coordinate data respectively generated in steps (B), (D) and (E).

10. The method of claim 7 wherein step (B) is performed by the substeps of generating said first set of coordinate data, using information regarding said spacecraft orbit and a fourth set of coordinate data, said fourth set of coordinate data having an almanac of the position of said terrestrial body relative to time.

11. The method of claim 7 wherein said first set of coordinate data is defined as a position vector, relative to said spacecraft orbit, having the following representation: ##EQU14##

17. The method of claim 7 wherein step (F) is performed by the substep of defining a set of spacecraft attitude variables in terms of said measurement from step (A) and said first, second

and third sets of coordinate data, said attitude variables defining the roll pointing error, the pitch pointing error, and the yaw pointing error of said spacecraft, respectively.

18. The method of claim 17 wherein step (F) is performed by the substep of forming a system of equations using said set of spacecraft attitude variables, said averaged and normalized set of coordinate data in claim 16 and said averaged and normalized set of coordinate data in claim 17.

19. The method of claim 18 wherein step (F) is performed by the substep of solving said system of equations to determine a set of values for said attitude variables.

20. The method of claim 19 wherein step (F) is performed by the substep of determining said attitude of said spacecraft from said values for said attitude variables.

21. A method of determining the three axis attitude of a spacecraft in a preselected orbit, using star trackers on said spacecraft, an on-board star catalog and a terrestrial sensor on said spacecraft, comprising the steps of:

(A) measuring the position of a terrestrial body with respect to said spacecraft, using said terrestrial sensor by measuring the nadir of said terrestrial body;

(B) generating a first set of coordinate data using information regarding said spacecraft orbit and a second set of coordinate data, said second set of coordinate data having an almanac of the position of said terrestrial body relative to time, said first set of coordinate data defining the position of said terrestrial body relative to said spacecraft orbit;

(C) measuring the positions of each of a plurality of stars with respect to said star trackers, using said star trackers by acquiring and tracking said plurality of stars as said stars pass through the field of vision of said star trackers;

(D) generating a third set of coordinate data using the positions measured in step (C) by transforming a fourth set of coordinate data into said third set of coordinate data, said fourth set of coordinate data defining the positions measured in step (C), said third set of coordinate data defining the positions of said stars relative to said spacecraft;

(E) identifying each star measured in step (C), using said star tracker and said on-board star catalog by tracking said stars and comparing tracking information to information contained in said star catalog;

(F) generating a fifth set of coordinate data using the identification of each star from (E), said fifth set of coordinate data defining the positions of said stars relative to said spacecraft orbit;

(G) averaging and normalizing the third set of coordinate data in step (D) to determine a single averaged and normalized representation of said third set of coordinate data;

(H) averaging and normalizing the fifth set of coordinate data in step (F) to determine a single average and normalized representation of said fifth set of coordinate data;

(I) defining a set of spacecraft attitude variables in terms of said measurement from step (A) and said first, third and fifth sets of coordinate data, said attitude variables defining the roll pointing error, the pitch pointing error, and the yaw pointing error of said spacecraft, respectively;

(J) forming a system of equations using said set of spacecraft attitude variables and said averaged and normalized representations of said third and fifth sets of coordinate data in steps (G) and (H), respectively;

(K) determining a set of value data for said attitude variables by solving the system of equations in step (J); and

(L) determining said attitude of said spacecraft from the set of value data in step (K).

22. The method of claim 21 wherein step (D) is performed by the substeps of transforming said fourth set of coordinate data into said third set of coordinate data by using a first direction

cosine transformation matrix, said first transformation matrix having the following notation: ##EQU15## where j=1, . . . , n (where n=the number of star trackers),

.alpha..sub.AZ,.sub.j =the azimuth mounting angle,

.epsilon..sub.EL,.sub.j =the elevation mounting angle, and

.delta..sub.R,.sub.j =the rotation mounting angle of said star tracker relative to said spacecraft.

25. The method of claim 21 wherein step (H) is performed by the substeps of averaging and normalizing said fifth set of coordinate data to determine an averaged and normalized representation of said fifth set of coordinate data, using the equation: ##EQU17## where j=the number of said star trackers;

k=the number of stars measured and identified by each star tracker;

r.sub.avg,j =said averaged and normalized representation of said fifth set of coordinate data; and

r.sub.k,j =said position of each said star relative to said spacecraft orbit.

26. The method of claim 21 wherein step (I) is performed by the substeps of defining a set of spacecraft attitude variables in terms of said measurement from step (A) and said first, third and fifth sets of coordinate data, said attitude variables defining arguments in a third direction cosine transformation matrix, said third transformation matrix being a transformation from coordinates relative to said spacecraft orbit to coordinates relative to said spacecraft and having the following notation: ##EQU18## where .phi.=the roll pointing error;

.theta.=the pitch pointing error, and

.PSI.=the yaw pointing error of said spacecraft, respectively.

28. The method of claim 27 wherein step (K) is performed by the substeps of determining a set of value data for said attitude variables by solving the system of linear equations in step (J) using least squares approximation.

29. A system for determining the 3-axis attitude of a spacecraft in a preselected orbit, comprising:

star sensing means on said spacecraft for sensing the position of stars relative to said sensing means, and for producing first signals representing said star positions;

earth sensing means on said spacecraft for sensing the position of the earth relative to said spacecraft, and for producing second signals representing said earth position, said earth sensing including a carbon dioxide band sensor for measuring the position of said earth relative to said spacecraft by measuring the nadir of the earth, said earth sensing producing said first signals, said first signals being digitized representations of said earth position relative to said spacecraft and said spacecraft orbit, respectively; and,

processing means for processing said first and second signals and for determining said 3-axis attitude of said spacecraft.

30. A system for determining the 3-axis attitude of a spacecraft in a preselected orbit, comprising:

star sensing means on said spacecraft for sensing the position of said stars relative to said sensing means, and for producing first signals representing said star positions; and

earth sensing means on said spacecraft for sensing the position of the earth relative to said spacecraft, and for producing second signals representing said earth position, said earth sensing means comprising RF ground beacon sensor for measuring the position of the earth relative to said spacecraft measuring the azimuth and elevation of a preselected ground station having known longitude and latitude location values on said earth, said earth sensing means producing said

first signals that are digitized representations of said earth position relative to said spacecraft and said spacecraft orbit, respectively.

31. A system for determining the 3-axis attitude of a spacecraft in a preselected orbit, comprising:

star sensing means on said spacecraft for sensing the positions of stars relative to said sensing means, and for producing first signals representing said star positions;

terrestrial body sensing means on said spacecraft for sensing the position of a terrestrial body relative to said spacecraft, and for producing said second signals representing said terrestrial body position; and,

processing means for processing said first and second signals for determining said 3-axis attitude of said spacecraft, said processing means including

(1) collecting and averaging means for collecting and averaging said first and second signals, and,

(2) estimating means for estimating a set of attitude variables using the least squares approximations of said attitude variables, said attitude variables defining said 3-axis attitude of said spacecraft.